

Personal Exposures, Indoor and Outdoor Air
Concentrations, and Exhaled Breath
Concentrations of Selected Volatile Organic
Compounds Measured for 600 Residents of
New Jersey, North Dakota, North Carolina and California

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Personal Exposures, Indoor and Outdoor Air Concentrations, and Exhaled Breath Concentrations of Selected Volatile Organic Compounds Measured for 600 Residents of New Jersey, North Dakota, North Carolina and California[†]

LANCE A. WALLACE

Visiting Scientist, Harvard University, Energy and Environmental Policy Center, 79 John F. Kennedy Street, Cambridge, MA 02138 U.S.A.

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EPA's TEAM Study has measured exposures to 20 volatile organic compounds in personal air, outdoor air, drinking water, and breath of 600 residents of New Jersey, North Carolina, North Dakota, and California. All participants were selected by a probability sampling scheme to represent a total of 700,000 inhabitants of seven cities. Participants carried a personal monitor to collect two 12-hour air samples and gave a breath sample at the end of the day. Two consecutive 12-hour outdoor air samples were also collected on identical Tenax cartridges in the backyards of some of the participants. About 7500 samples were collected, of which 2000 were quality control samples. Eleven compounds were often present in air. Personal exposures were consistently higher than outdoor concentrations. Indoor sources appeared responsible for much of the difference. Breath concentrations also usually exceeded outdoor concentrations, and correlated more strongly with personal exposures than with

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outdoor concentrations. Some activities (smoking, visiting dry cleaners or service stations) and occupations (chemical, paint, and plastics plants) were associated with significantly elevated exposures and breath levels for certain toxic chemicals. Residence near major point sources did not affect exposure.

KEY WORDS: Volatile organic compounds, personal exposures, indoor air concentration, outdoor air concentration, total exposure assessment methodology (TEAM) GC/MS.

INTRODUCTION

The TEAM (Total Exposure Assessment Methodology) Study was planned in 1979 and completed in 1985.¹⁻⁷ The goals of this study were: (1) to develop methods to measure individual total exposure (exposures through air, food, and water) and resulting body burden of toxic and carcinogenic chemicals, and (2) to apply these methods within a probability-based sampling framework to estimate the exposures and body burdens of urban populations in several U.S. cities. To achieve these goals, the following approach was adopted:

- 1) A small personal sampler was developed to measure personal exposure to airborne toxic chemicals;
- 2) A specially-designed spirometer was developed to measure the same chemicals in exhaled breath;
- 3) A survey design involving a three-stage stratified probability selection approach was adopted to insure inclusion of potentially highly exposed groups.

STUDY DESIGN

The main TEAM Study measured the personal exposures of 600 people to a number of toxic or carcinogenic chemicals in air and drinking water. The subjects were selected to represent a total population of 717,000 residents of cities in New Jersey, North Carolina, North Dakota, and California.

Each participant carried a personal sampler during normal daily activities for two consecutive 12-hour periods. An identical sampler operated in the backyards of about 150 of the 600 participants'

homes for the same two 12-hour periods. Two drinking water samples were also collected for each participant. At the end of the 24-hour sampling period, a sample of exhaled breath, which was analyzed for the same compounds, was collected for each participant. All participants also completed questionnaires about their age, sex, occupations, and activities during the sampling period. An extensive quality assurance program was implemented for all sampling/analysis activities.

Five thousand five hundred and fifty households located in 108 areas in two New Jersey cities (Elizabeth and Bayonne) were polled to collect data on age, sex, occupation, and smoking status of 11,400 residents. A stratified probability sample of these individuals yielded 355 participants. The probability-based survey design provides a basis for robust inferences to the approximately 128,000 members of the target population—individuals who were residents of the target cities and over six years of age when the study was conducted in the fall of 1981.

A return visit was made to 157 of the original participants in the summer of 1982, and a final visit was made to 49 of these 157 persons in January–February of 1983. The individuals contacted on each return visit were a probability sample of the participants from the previous visit.

A small comparison study was undertaken in Greensboro, North Carolina in May 1982. Greensboro was selected because its population is similar in size to the Bayonne–Elizabeth area and it has similar small industries, but no chemical manufacturing or petroleum refining operations. The target sample size was set at 25 for a three-stage sample survey design to represent 131,000 Greensboro residents. Monitoring methods were identical to those employed in New Jersey.

A second comparison site was selected to investigate whether the population of a small, rural, agricultural town far from any industry would exhibit personal exposures clearly different from those of the Northern New Jersey population. Once again, the target sample size was set at 25 subjects to represent approximately 7000 residents of Devils Lake, North Dakota.

Between February 3 and March 2, 1984, 117 residents selected from 1063 households representing 360,000 residents in the South Bay section of Los Angeles participated in the study. The second

Los Angeles trip (May 21–June 2, 1984) included 52 participants, all of whom had participated in the first season study. The final trip (June 8–June 25, 1984) included 71 residents of Antioch and Pittsburg, California selected from 502 households representing a population of 91,000.

Table I summarizes the target locations and seasons of the TEAM Study, as well as the numbers of participants for each location/season.

TABLE I
Sites visited in the main TEAM study.

Site visit code	Location	Time of visit	No. of respondents	Population represented
NJ1	Bayonne & Elizabeth, NJ	Sept–Nov 1981	335	128,000
NJ2	Bayonne & Elizabeth, NJ	July–Aug 1982	157 ^a	109,000
NJ3	Bayonne & Elizabeth, NJ	Jan–Feb 1983	49 ^b	94,000
NC	Greensboro, NC	May 1982	24	131,000
ND	Devils Lake, ND	Oct 1982	24	7,000
LA1	Los Angeles, CA	Feb 1984	117	360,000
LA2	Los Angeles, CA	May 1984	52 ^c	333,000
CC	Contra Costa County, CA (Antioch and Pittsburg)	June 1984	71	91,000
Total	7 cities		591	717,000

^aSubset of NJ1 respondents.

^bSubset of NJ2 respondents.

^cSubset of LA1 respondents.

Response rates

In New Jersey, 5578 homes were screened with an 85% completion rate. A total of 852 persons were selected to participate of which 693 were eligible, with 355 (51%) completing the study. The overall response rate is a product of the rates at each stage. Thus, the New Jersey rate (first visit) is $85\% \times 51\% = 43\%$. The return visits to the New Jersey respondents showed successively higher response rates of 79% and 91%. The North Carolina overall response rate was 76% and the North Dakota rate was 64%.

In California, 1864 homes were screened (1260 in Los Angeles, 604

in Antioch and Pittsburg) with an 88% completion rate. From the information collected on more than 5000 residents of these homes, a total of 311 were selected to participate, of which 293 were eligible, with 188 (64%) completing the study. Thus, the overall response rate was 56% ($88\% \times 64\%$).

Measurement methods

Personal and outdoor air samplers employed a glass cartridge containing the solid granular sorbent Tenax-GC. A small DuPont pump drew air at ~ 30 mL/min through the cartridge for ~ 12 hrs to collect a target volume of 20 L. A sampling vest was designed to hold the pump and the cartridge close to breathing level while leaving the participant's hands free for normal activities.

Breath samples were collected using a specially-designed spirometer mounted in a van. The subject provided the breath sample at his home in the evening (6–9 pm) at the end of the 24-hour sampling period.

Water samples were collected from the tap at each participant's home after a 20-sec flushing period. Samples were collected in 2 oz glass jars containing sodium thiosulfate to quench residual chlorine reactions.

Air and breath samples were analyzed by capillary gas chromatography mass spectrometry (GC-MS) techniques followed by a combination of manual and automated analyses of spectra. Water samples were analyzed by a purge and trap GC method utilizing a Hall Electroconductivity detector for halogenated compounds and a flame ionization detector for aromatics.

A total of nearly 7000 air, breath, and drinking water samples were collected for 600 respondents (850 person-days) in all sites. This represented about 96% of all samples originally scheduled.

Quality of the data

An extensive quality assurance (QA) program was carried out. About 30% of all samples were either blanks, spikes, or duplicates. Analysis of each medium (air, water, breath) was repeated for 10% of samples in external QA laboratories (IIT Research Institute and the University of Miami Medical School). Audits of all laboratory

activities were undertaken by EPA's Environmental Monitoring Systems Laboratory at Research Triangle Park, North Carolina (EMSL-RTP) and spiked samples were supplied by EMSL-RTP (air) and EPA's Environmental Monitoring and Support Laboratory in Cincinnati (water). A separate QA report was written by an independent laboratory (Northrop Corporation) concluding that no significant analytical differences could be found among the three air monitoring laboratories (Research Triangle Institute, IIT Research Institute, and EMSL-RTP).

Precision. Results of the duplicate analyses for eleven prevalent target compounds in air and breath samples indicate that median coefficients of variation (CV) ranged from 20-40% during most visits, with considerable improvement in the California stage of the study.

The precision for most targets in personal air samples was consistently superior to the same compounds in breath samples. However, one analyte, benzene, gave poor precision at several sites. This was probably due in part to its chronic high and variable background levels on the blank Tenax cartridges. Certain aromatic target compounds were normally associated with the best precision: styrene, xylenes, ethylbenzene, and the dichlorobenzene isomers.

In general, precision for water samples was excellent (< 10% CV).

Blank backgrounds. Background levels found on field blanks were acceptably low (the equivalent of less than $0.5 \mu\text{g}/\text{m}^3$) with the exception of benzene and 1,1,1-trichloroethane on some trips. Considerable improvements were evident in comparing field blanks collected in the first trip to Los Angeles with those collected in New Jersey. Benzene blank values improved from 97 ng/cartridge to 26; 1,1,1-trichloroethane from 33 to 5; and chloroform and *p*-xylene from 22 to 3 each.

Recoveries. Recoveries of most chemicals ranged between 80 and 120% in both Los Angeles and New Jersey. In general, target compound recoveries from water were acceptable and backgrounds nearly nonexistent.

Deuterated benzene, chlorobenzene, and ethylbenzene samples were prepared and recovery efficiencies calculated to determine unambiguously how much of the original spiked compound is lost

and how much is gained by contamination during transportation and storage. Results indicated no serious losses or gains for these three chemicals.

Performance audits. EPA spiked the Tenex cartridges (provided by RTI) with nine target compounds. These performance audit samples were submitted blind to the RTI analyst. The observed biases associated with most of the target chemicals during all trips were less than $\pm 35\%$ except for the North Dakota samples, which exhibited the highest bias, apparently due to a substandard batch of Tenax.

The performance audit water samples were provided by EMSL/EPA in Cincinnati. In general, recoveries ranged from 80–90%. Bromine containing targets were recovered less completely (40–75%).

RESULTS

Percent measurable

All measurements were classified into three groups: nondetectable, trace, and measurable. Nondetectable values were those falling below the Limit of Detection (LOD). Trace values exceeded the LOD, but fell below the Quantifiable Limit (QL), generally chosen to be 4 times the LOD. Measurable values exceeded the QL. For air and breath samples, the QL varies with volume collected and with the chemical—however in most cases the QL was of the order of $1 \mu\text{g m}^{-3}$.

For New Jersey, the target chemicals may be sorted into several categories based on the percent of samples exceeding the QL. The first class, ubiquitous chemicals that were found in 33–100% of all air and breath samples, includes two common solvents (1,1,1-trichloroethane and tetrachloroethylene); several aromatic compounds (benzene, the xylene isomers, and ethylbenzene); and two isomers of dichlorobenzene, used in moth crystals and deodorizers.

The second class, compounds often but not always found in all sample types, includes one additional solvent (trichloroethylene); a compound mainly found in drinking water (chloroform); and another aromatic compound (styrene). The sources of styrene and dichloro-

benzenes may have been in the home, based on the much greater frequencies of measurable amounts in personal air samples (70-80%) compared to outdoor air samples (20-40%).

The third class of substances were only occasionally found (<10% measurable in most sample types). This class includes ethylene dichloride, vinylidene chloride, carbon tetrachloride, bromodichloromethane, chlorobenzene, and *o*-dichlorobenzene.

Finally, three brominated substances were almost never found in air or breath: bromoform, dibromochloromethane, and dibromochloropropane.

Fewer target chemicals were found in drinking water in New Jersey, and only the three trihalomethanes were ubiquitous. A second group of three solvents appeared at low levels in nearly all tap water samples collected in Elizabeth but in few of the Bayonne samples.

For the personal air and breath samples collected at the two comparison sites in Greensboro, North Carolina and Devils Lake, North Dakota, most of the prevalent chemicals in New Jersey air and breath samples were again found. Only carbon tetrachloride appeared considerably less often than in New Jersey. In water samples, the same chemicals (trihalomethanes) were detected as in New Jersey.

In California, nine target chemicals were added and three were dropped. All 26 target chemicals were found in at least a few air or water samples. Many were present in nearly every air or breath sample. The ten prevalent airborne chemicals in New Jersey were also prevalent in California; in addition, six of the nine new target chemicals were also present much of the time.

In drinking water bromoform appeared in 70-90% of the samples, compared to almost none of the New Jersey water samples. Once again, the common solvents (trichloroethylene, tetrachloroethylene, and 1,1,1-trichloroethane) were present but at very low levels.

Concentrations

New Jersey. Mean concentrations of 11 prevalent chemicals in personal air, outdoor air, and exhaled breath samples collected during all three seasons in New Jersey are listed in Table II. In all

TABLE II
Estimates of air and breath concentrations of 11 prevalent compounds for 130,000 residents (Fall 1981), 110,000 residents (Summer 1982) and 49,000 residents (Winter 1983)—Elizabeth and Bayonne, NJ.

Compound	Fall 1981			Summer 1982			Winter 1983		
	Personal air (N = 340)	Outdoor air (86)	Breath (300)	Personal air (150)	Outdoor air (60)	Breath (110)	Personal air (49)	Outdoor air (9)	Breath (49)
1,1,1-Trichloroethane	94 ^a	7.0 ^a	15 ^b	67	12	15	45	1.7	4.0
<i>m,p</i> -Dichlorobenzene	45	1.7	8.1	50	1.3	6.3	71	1.2	6.2
<i>m,p</i> -Xylene	52	11	9.0	37	10	10	36	9.4	4.7
Tetrachloroethylene	45	6.0	13	11	6.2	10	28	4.2	11
Benzene	28	9.1	19	NC ^c	NC	NC	NC	NC	NC
Ethylbenzene	19	4.0	4.6	9.2	3.2	4.7	12	3.8	2.1
<i>o</i> -Xylene	16	4.0	3.4	12	3.6	5.4	13	3.6	1.6
Trichloroethylene	13	2.2	1.8	6.3	6.8	5.9	4.6	0.4	0.6
Chloroform	8.0	1.4	3.1	4.3	13	6.3	4.0	0.3	0.3
Styrene	8.9	0.9	1.2	2.1	0.7	1.6	2.4	0.7	0.7
Carbon tetrachloride	9.3	1.1	1.3	1.0	1.0	0.4	ND ^d	ND	ND
Total (11 compounds)	338	48	80	200	59	66	216	25	31

^aAverage of arithmetic means of day and night 12-hour samples ($\mu\text{g m}^{-3}$).

^bArithmetic mean.

^cNot calculated—high background contamination.

^dNot detected in most samples.

cases, personal air values exceeded outdoor air values, by ratios of 2 to 5. Breath concentrations also often exceeded outdoor air values. The highest indoor air concentrations exceeded the highest outdoor air concentrations by factors of 10 or 20.

Drinking water concentrations of chloroform were highest in summer and fall, decreasing sharply in winter. The higher indoor than outdoor air values continued to be observed in the summer and winter seasons. The indoor-outdoor ratios for most chemicals increased from summer to fall to winter.

Greensboro. Personal air exposures were again greater than outdoor air exposures for most of the target chemicals, although the small number of outdoor air samples makes this only a tentative conclusion. A large range in personal air exposures and breath concentrations was again evident, although mean daytime personal air values were somewhat below those observed in the winter season in New Jersey.

Devils Lake. Personal air exposures again exceeded outdoor air concentrations for all target compounds, although caution is indicated since the number of outdoor air samples was extremely small. Most chemicals were not measurable in outdoor air, but indoor levels remained comparable to those observed in Greensboro. Drinking water concentrations of chloroform were exceedingly low ($<1 \mu\text{g/L}$).

Los Angeles—February 1984. The highest weighted 24-hour personal air exposures (Table III) were to 1,1,1-trichloroethane, *m,p*-xylene, *m,p*-dichlorobenzene, benzene, and tetrachloroethylene. Outdoor concentrations, particularly at night, were unusually high, exceeding daytime outdoor levels by 50% or more. Breath means ranged from 10–30% of personal exposures for most chemicals except tetrachloroethylene (75%) and benzene (45%).

Los Angeles—May 1984. Concentrations, both personal and outdoor, were considerably reduced. However, the same chemicals appeared in roughly the same order. Outdoor overnight values no longer exceeded day time levels, and personal exposures nearly always exceeded outdoor concentrations.

TABLE III
Estimates of air and breath concentrations of nineteen prevalent compounds for 360,000 Los Angeles residents (February 1984),
330,000 Los Angeles residents (May 1984) and 91,000 Contra Costa residents (June 1984).

Compound	LA1			LA2			CC		
	Personal air (N = 115)	Outdoor air (24)	Breath (110)	Personal air (50)	Outdoor air (24)	Breath (24)	Personal air (68)	Outdoor air (10)	Breath (67)
1,1,1-Trichloroethane	96 ^a	34 ^a	39 ^b	44	5.9	23	16	2.8	16 ^c
<i>m,p</i> -Xylene	28	24	3.5	24	9.4	2.8	11	2.2	2.5
<i>m,p</i> -Dichlorobenzene	18	2.2	5.0	12	0.8	2.9	5.5	0.3	3.7
Benzene	18	16	8.0	9.2	3.6	8.8	7.5	1.9	7.0
Tetrachloroethylene	16	10	12	15	2.0	9.1	5.6	0.6	8.6 ^c
<i>o</i> -Xylene	13	11	1.0	7.2	2.7	0.7	4.4	0.7	0.6
Ethylbenzene	11	9.7	1.5	7.4	3.0	1.1	3.7	0.9	1.2
Trichloroethylene	7.8	0.8	1.6	6.4	0.1	1.0	3.8	0.1	0.6
<i>n</i> -Octane	5.8	3.9	1.0	4.3	0.7	1.2	2.3	0.5	0.6
<i>n</i> -Decane	5.8	3.0	0.8	3.5	0.7	0.5	2.0	3.8	1.3
<i>n</i> -Undecane	5.2	2.2	0.6	4.2	1.0	0.7	2.7	0.4	1.2
<i>n</i> -Dodecane	2.5	0.7	0.2	2.1	0.7	0.4	2.1	0.2	0.4
α -Pinene	4.1	0.8	1.5	6.5	0.5	1.7	2.1	0.1	1.3
Styrene	3.6	3.8	0.9	1.8	—	—	1.0	0.4	0.7
Chloroform	1.9	0.7	0.6	1.1	0.3	0.8	0.6	0.3	0.4
Carbon tetrachloride	1.0	0.6	0.2	0.8	0.7	0.2	1.3	0.4	0.2
1,2-Dichloroethane	0.5	0.2	0.1	0.1	0.06	0.05	0.1	0.05	0.04
<i>p</i> -Dioxane	0.5	0.4	0.2	1.8	0.2	0.05	0.2	0.1	0.2
<i>o</i> -Dichlorobenzene	0.4	0.2	0.1	0.3	0.1	0.04	0.6	0.07	0.08
Total (19 compounds)	240	120	80	150	33	56	72	16	62

^aAverage of arithmetic means of day and night 12-hour samples ($\mu\text{g m}^{-3}$).

^bArithmetic mean.

^cOne very high value removed.

Antioch and Pittsburg—June 1984. Weighted air and breath exposures were lower than in Los Angeles, but again the same five chemicals were responsible for the highest exposures.

Correlations of personal air exposures with breath concentrations. Ten of the eleven prevalent chemicals in the breath of the 355 New Jersey residents were significantly correlated (most at probabilities $p < 0.0001$) with the previous 12-hour average air exposures. (The 11th chemical, chloroform, showed a significant correlation between breath and drinking water concentrations.) Correlations between breath and personal air exposures continued to be significant for some chemicals (xylenes, trichloroethylene, tetrachloroethylene, and *p*-dichlorobenzene) at most or all TEAM Study sites.

DISCUSSION

For the concentrations in air and breath described above, several observations are evident:

1) *Exposures were highly variable.* For many chemicals, the range in personal air exposures exceeded a factor of 1000 or even 10,000. This was far greater than for typical criteria pollutants such as carbon monoxide and suspended particulates. The range in breath concentrations was almost equally variable, indicating that the higher exposures may have been producing a higher body burden.

2) *All prevalent chemicals had higher personal air concentrations than outdoor air concentrations.* This is the case even for overnight exposures, when participants were normally at home for the entire 12 hours. A partial exception to this rule occurred in Los Angeles in winter, where strong inversions elevated mean outdoor levels to near-equality with indoor means; however, maximum personal exposures always maximum outdoor concentrations.

3) *Breath levels were also often higher than outdoor levels.* Since levels in exhaled breath are often only 20–40% of total intake, the remainder being metabolized or excreted through other pathways, the breath levels imply exposures several times greater. This is further indication that exposures are higher than would be expected from observed outdoor concentrations.

4) *The ratio of personal exposures to outdoor levels increased with higher exposures. This can be illustrated by comparing indoor overnight exposures (when persons were almost invariably inside their homes) to outdoor overnight concentrations for the 75th percentile and the 99th percentile of each distribution. The ratios increased from 2-5 at the 75th percentile up to 10-20 at the 99th percentile for most of the target chemicals.*

5) *The higher overnight personal exposures appear to implicate the home or personal activities within the home as the major source of exposure to these eleven compounds. The daytime personal air exposures were usually the highest, as expected since this time period included the commuting and occupational activities. However, the overnight personal air exposures, when people were normally sleeping, were nearly as high. In fact, all prevalent chemicals had much higher overnight indoor concentrations than overnight outdoor concentrations, sometimes 100 times higher for individual paired observations.*

6) *The presence or absence of a source is a far stronger determinant of indoor air concentrations than the air exchange rate. Although air exchange rates were not measured, many studies indicate that the range of rates is quite small. Yet homes may differ by a factor of 100 in concentration.*

7) *Only chloroform and possibly bromodichloromethane were important contributors to total exposure from drinking water in the study area during the first season. The median value for chloroform in drinking water was 67 $\mu\text{g/L}$; in air, 3.2 $\mu\text{g/m}^3$. Assuming 2 L of water intake per day and 20 m^3 of air intake per day, the median intake of chloroform in water (134 μg) was about twice that in air (64 μg). (However, if the water was boiled for tea or coffee, it would lose its chloroform—thus the water intake may be overestimated.) Drinking water also accounted for most exposure to bromodichloromethane, since the chemical was detected in only 3% of the personal air samples.*

Relationship of benzene and other aromatics to smoking

Benzene concentrations in air and breath were significantly different for smokers and non-smokers. Median daytime air exposures in the

fall of 1981 were $21 \mu\text{g}/\text{m}^3$ for smokers, $12 \mu\text{g}/\text{m}^3$ for nonsmokers. Breath medians were $22 \mu\text{g}/\text{m}^3$ for smokers, $7.9 \mu\text{g}/\text{m}^3$ for nonsmokers.

Three other aromatics (*p*-xylene, ethylbenzene, and styrene) also showed significantly elevated levels in the breath of smokers compared to nonsmokers during all three seasons. (The fifth aromatic, *o*-xylene, was elevated, but usually not significantly.) Two laboratory studies have identified these five aromatic components in sidestream smoke⁸ and mainstream smoke.⁹

Smokers generally had 2–4 times as much benzene in their breath as nonsmokers. Also, benzene levels in the homes containing smokers were 30–50% higher than in nonsmoking households. Since about 60% of U.S. children live in homes with smokers, it appears possible that a large number of children have increased exposure to benzene, a known leukemogen, during their early years. A recent study by Sandler¹⁰ comparing lifetime cancer mortality rates of persons who were exposed or were not exposed as children to parental smoking showed significant increases in hematopoietic (leukemia, lymphomas, etc.) mortality rates in the exposed group. The odds ratio increased from 1.7 with one parent smoking to 4.6 with both parents smoking.

Uncertainty of estimates

The uncertainty in the estimates of personal exposures of the target population consists of two parts: survey sampling uncertainty and measurement errors. For a simple random sample size of 350 persons, assuming a log-normal distribution, standard sampling theory states that the estimate of the median will be 95% certain to lie between the 44th and 56th percentiles.¹¹ Since our sample is clustered, the design effects will broaden these ranges of uncertainty by a small amount. The corresponding range for the summer group of 160 persons is 41–59%; and for the winter group of 50 persons, 35–65%.

The second source of uncertainty is measurement error. Analysis of the duplicate measurements for all three seasons using a method developed by the author and based on observations in Evans¹² resulted in corrected frequency distributions of exposures with geometric standard deviations 5–20% less than the observed geometric standard deviations.

Effects of residence and occupation on exposure

Effect of city (NJ). Student "t"-tests on the geometric means indicated that few chemicals showed significant differences between cities.

Day-Night and Weekday-Weekend differences. All chemicals were tested for day-night and weekday-weekend differences. (All tests were carried out on the logarithms of the concentrations.) Only one chemical, tetrachloroethylene, showed fairly consistent day-night differences, displaying 50-60% higher concentrations in both personal and outdoor air in the fall season. Tetrachloroethylene was also the only chemical to show strong weekday increases in both daytime and overnight outdoor air.

Proximity to point sources. In New Jersey, census tracts were classified as high and low exposure strata depending on whether they were within 1.5 km of suspected point sources or not. Those strata bordering the high exposure strata and containing major highways as well were classified as moderate exposure. In general, few differences in percent measurable or concentrations in air and breath were seen between the high, moderate, and low proximity strata.

Occupational exposure. About 85 of the 350 participants were classified as having potential occupational exposures to some of the target compounds. Eleven of 14 occupations showed significant ($p < 0.05$, Mann-Whitney nonparametric test) increases in breath concentrations or personal air exposures to some chemicals.

Effects of activities and potential sources on exposures

All participants were asked if they had been exposed to potential sources of target chemicals on the day they were monitored or within the previous week. Sources included industrial plants, auto exhaust, and paint. For ten of the twelve sources, at least one (and as many as six) of the eleven most prevalent chemicals appeared at significantly higher levels in the breath of persons exposed during the day or week compared to those not exposed to the source. In most cases, the chemicals that were elevated were those expected to be

associated with a given source, such as tetrachloroethylene with dry cleaners and benzene with service stations or with auto exhaust.

A second series of questions concerned direct exposure to chemical groups or mixtures. These chemical mixtures included solvents, pesticides, and tobacco smoke. Again, certain chemicals appeared at significantly higher levels in the breath of exposed persons compared to those not exposed.

Thus, breath analysis alone was effective in detecting increased exposures due to specific sources or chemical mixtures. The magnitude of the increase ranged from 30–50% up to factors of three or higher.

Personal air exposures to certain chemicals were also significantly elevated for persons recently exposed to potential sources compared to persons not exposed to that source.

Since many chemicals have multiple sources, some members of the so-called "unexposed" groups in the above analyses may have been exposed to the same chemical through a different source, thus blurring the distinction between exposed and unexposed groups. Therefore, the breath and personal air levels of groups exposed to each source were compared to the group of persons who responded that they were not exposed to *any* source. As could be expected, the number of chemicals showing significant differences increased considerably. The number showing simultaneously elevated air and breath values doubled.

Stepwise regressions. A stepwise regression was carried out on the logarithms of the chemical concentrations as functions of individual activities, occupations, or household characteristics as determined from the questionnaires—a total of 70 independent variables.

Smoking and specific occupations continued to appear as the strongest determinants of personal exposures (Table IV). Passive smoking (having a smoker in the household) was also a significant contributor to exposures to benzene, styrene, and xylenes. Common activities such as filling gasoline tanks and visiting a dry-cleaners or paint store were also significantly associated with higher exposures.

The number and strength of many of the associations leads us to the following conclusion: Breath levels and personal air exposures to certain toxic and carcinogenic chemicals are significantly elevated in persons exposed to potential sources (consumer products, activities, and workplaces).

TABLE IV

Activities, occupations, or household characteristics associated with significantly increased exposures in air or exhaled breath to eleven prevalent chemicals in New Jersey.

Chemical	Rank	Activity ^a	p ^b
Benzene	1	Smoking	0.00001
	2	Having a smoker in the home	0.0006
	3	Being exposed to smokers	0.02
	4	Visiting a dry cleaners	0.03
	5	Traveling in a car	0.04
Styrene	1	Smoking	0.00001
	2	Having a smoker in the home	0.0001
	3	Working at a plastics plant	0.0005
	4	Exposed to paints	0.002
	5	Working at/being in a paint store	0.005
	6	Working at a chemical plant	0.007
	7	Building scale models	0.007
	8	Painting as a hobby	0.009
	9	Being nonwhite	0.01
	10	Metalworking	0.02
	11	Working with degreasers	0.03
Ethylbenzene	1	Smoking	0.0001
	2	Exposed to high dust/particle levels	0.0002
	3	Having a smoker in the home	0.0006
	4	Working with solvents	0.001
	5	Wood processing	0.001
	6	Working at a service station	0.002
	7	Having a chemical worker in the home	0.002
	8	Employed	0.002
	9	Living in a home < 1 yr	0.003
	10	Pumping gas	0.005
	11	Metalworking	0.005
	12	Working at a scientific lab	0.005
	13	Refinishing furniture as a hobby	0.01
	14	Working with dyes	0.01
	15	Having a metal worker in the home	0.02
	16	Working with odorous chemicals	0.02
	17	Having a furniture refinisher in the home	0.04
<i>m, p</i> -Xylene	1	Employed	0.0001
	2	Smoking	0.0001
	3	Wood processing	0.0001
	4	Working at a service station	0.0001

TABLE IV (continued)

	5	Having a chemical worker in the home	0.0001
	6	Working with solvents	0.0003
	7	Having a smoker in the home	0.0006
	8	Living in an old home (> 10 yrs)	0.002
	9	Living in a home < 1 yr	0.003
	10	Pumping gas	0.006
	11	Metalworking	0.008
	12	Exposed to high dust/particle levels	0.01
	13	Having a furniture refinisher in the home	0.02
	14	Furniture refinishing	0.03
<i>o</i> -Xylene	1	Wood processing	0.0001
	2	Employed	0.0001
	3	Working with solvents	0.0008
	4	Working with odorous chemicals	0.001
	5	Pumping gas	0.002
	6	Metalworking	0.003
	7	Having a chemical worker in the home	0.003
	8	Having a smoker in the home	0.005
	9	High dust/particle levels	0.006
	10	Having a furniture refinisher in the home	0.006
	11	Living in an old home (> 10 yrs)	0.007
	12	Furniture refinishing	0.02
	13	Aged between 40 and 65	0.03
1,1,1-Trichloroethane	1	Wood processing	0.0001
	2	Employed	0.0001
	3	Metalworking	0.006
	4	Working at a textile plant	0.007
	5	Having a metal worker in the home	0.008
	6	Having a chemical worker in the home	0.009
Trichloroethylene	1	Wood processing	0.002
	2	Working at a plastics plant	0.003
	3	Gas furnace	0.01
	4	Working at a scientific lab	0.01
	5	Smoking	0.02
Tetrachloroethylene	1	Employed	0.0001
	2	Wood processing	0.0002
	3	Visiting a dry cleaners	0.003
	4	Working at a textile plant	0.01
	5	Using pesticides	0.01
	6	Working at/being in a paint store	0.03
	7	Being male	0.04

TABLE IV (continued)

Carbon tetrachloride	1	Aged less than 17	0.0005
	2	Metalworking	0.006
	3	Working at/being in a paint store	0.02
	4	Furniture refinishing	0.03
<i>m, p</i> -Dichlorobenzene	1	Working at a hospital	0.0001
	2	Having central air conditioning	0.004
	3	Treating home with pesticides	0.05
Chloroform	1	Working at/being in a paint store	0.007
	2	Using pesticides	0.02

^aBased on questionnaire data from 350 subjects in Bayonne-Elizabeth, New Jersey - Fall 1981.

^bProbability that the association is due to chance.

It seems clear that many indoor sources of toxic organics exist; however, few have been unequivocally identified and fewer still have had their source emission rates estimated.¹³ Identification of indoor sources from among thousands of consumer products and building materials is required to allow a better estimate of possible risks to public health and corrective actions that can be taken.

Breath. Breath is an important mode of intake and excretion for many volatile compounds.¹⁴ The compounds measured in the exhaled breath of persons breathing pure air have been supplied by the blood stream as it passed through the lungs. The advantages of measuring breath rather than blood are (1) the technique is non-invasive and therefore preferable for use in studies requiring reasonable response rates from general public volunteers; and (2) the measurement technique employed (Tenax; GC/MS analysis) is more sensitive than the corresponding technique for blood employed in the first (pilot study) phase of the TEAM Study. In fact, scores of compounds were quantified in breath using this technique but only one (chloroform) was quantified regularly in blood during the TEAM pilot study.

SUMMARY AND CONCLUSIONS

The major findings of the TEAM Study may be summarized as follows:

1) Measurement of personal exposures using the Tenax personal monitors was shown to be a feasible approach, acceptable to essentially all subjects (ages 7 to 85), and capable of detecting exposures to most of the target compounds at normal environmental concentrations.

2) Measurement of exhaled breath proved to be a sensitive and noninvasive way to determine body burden.

3) Mean personal air exposures to essentially every one of the eleven prevalent target chemicals were greater than mean outdoor concentrations at 7 of 8 locations/monitoring periods. (The one exception was Los Angeles in February, where strong overnight inversions led to elevated outdoor concentrations.) The upper 10% of personal exposures always exceeded the upper 10% of outdoor concentrations for all sites and time periods.

4) A major reason for these higher personal exposures appears to be elevated indoor air levels at work and at home.

5) The elevated indoor air levels appear to be due to a variety of sources, including consumer products, building materials, and personal activities.

6) The breath levels correlated significantly with personal air exposures to nearly all chemicals but did *not* correlate with outdoor air levels. This is further corroboration of the relative importance of indoor air compared to outdoor air.

7) A number of specific sources of exposure were identified including:

- a) Smoking (benzene, xylenes, ethylbenzene, styrene in breath)
 - b) Passive smoking (same chemicals in indoor air)
 - c) Visiting dry cleaners (tetrachloroethylene in breath)
 - d) Auto exhaust (benzene in breath)
 - e) Various occupations, including: chemicals, plastics, wood processing, scientific laboratories, garage or repair work, metal work, printing, etc. (mostly aromatic chemicals in daytime personal air)
- 8) Other sources were hypothesized, including:
- a) Hot showers (chloroform in indoor air)
 - b) Room air fresheners or moth crystals (*p*-dichlorobenzene in indoor air)

9) In most cases, these sources far outweighed the impact of traditional "major" point sources (chemical plants, petroleum refineries, petrochemical plants) and area sources (dry cleaners and service stations) on personal exposure.

10) For all chemicals except the trihalomethanes, the air route provided >99% of the exposure. Water provided nearly all of the exposure to the three brominated trihalomethanes, and more than half of most personal exposures to chloroform.

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